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An ecological classification of Alaskan Steller sea lion (*Eumetopias jubatus*) rookeries: A tool for conservation/management

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ABSTRACT

As the western stock of Steller sea lions continues to decline, government managers may place additional controls on commercial fisheries as protective measures. Currently, management decisions regarding rookeries are based largely on the geographic location of a site and little effort has been made to describe sea lion rookeries in an ecosystem context. We provide a broad ecological characterization of rookeries for the western stock of Steller sea lions, which can be used in making management decisions to facilitate their recovery. We gathered data on habitat (bathymetry, sea surface temperature, substrate type, and orientation), diet, and population trends from available literature and National Marine Fisheries Service databases (1990 - 1998), and we used a Geographical Information System (GIS) to group sea lion rookeries into ecologically related regions. Ecological attributes were assigned to rookeries within a 10 nm radius of land. Regions were determined using cluster analysis. Five distinct classes of rookeries (i.e. potential management regions) were identified based on their relatedness to the ecological factors we defined. Several of the regional breaks occur at major oceanic passes including Amchitka, Samalga, and Unimak passes and are associated with ocean currents.

Key Words: ecology, *Eumetopias jubatus*, GIS, rookery classification, Steller sea lions

INTRODUCTION

As Steller sea lions (*Eumetopias jubatus*) continue to decline in western Alaska (Loughlin *et al.*, 1992; Sease and Gudmundson, 2002), government managers may place additional constraints on the Alaskan commercial fishing industry to protect sea lions. Management measures already have taken the form of time and area restrictions and no-trawl zones near Steller sea lion rookeries in western Alaska (Fritz and Ferrero, 1998; Fritz *et al.*, 1995). These management restrictions near any particular rookery have been based principally on the geographical region which the site is located (e.g. Gulf of Alaska or Bering Sea) rather than on biological or oceanographic characteristics of the site. In a few instances management of a site was chosen based on historical and present abundance of animals during certain times of the year, but there has been no effort to characterize rookeries in a biological or ecosystem context for the purpose of management.

The North Pacific Ocean, Bering Sea, and Gulf of Alaska (GOA) are dynamic and highly productive systems (Hood and Zimmerman, 1987; Loughlin and Ohtani, 1999). However, the importance of the physical properties of these systems to sea lion distributions is poorly understood because of lack of integrated data sets on the appropriate spatial and temporal scales. Either directly or indirectly, the physical characteristics of these systems affect where sea lions forage and maintain rookeries and should be considered when making management decisions.

The status and trends of Steller sea lions in Alaska are typically reported in geographical units using natural geographic breaks, such as major oceanographic passes between islands, and clumping of islands in close geographic proximity (Calkins and Pitcher, 1982; Merrick *et al*., 1987). At a worldwide scale, Loughlin *et al.* (1984) grouped sea lion rookeries based on large geographic areas such as the Kuril Islands, Aleutian Islands, Alaska Peninsula, and south-central Alaska and data for range-wide survey and status of the population was reported accordingly (Loughlin *et al.*, 1992). However, when reporting the decline of sea lion abundance, Merrick *et al.* (1987) subdivided western Alaskan sea lion rookeries into four large areas based on island groupings: 1) central GOA, 2) western GOA, 3) eastern Aleutian Islands, and 4) central Aleutian Islands. National Marine Fisheries Service (NMFS) expanded this classification to the entire state of Alaska by adding four additional sub areas to the original format (Merrick *et al*. 1987) (Fig. 1). Loughlin and York (2000) used these eight sub-areas when accounting for sources of sea lion mortality.

Population census data at rookeries indicate that adjoining rookeries often have similar abundance trends. Expanding from a purely geographic approach for describing management units, York *et al*. (1996) used hierarchical cluster analysis to quantify metapopulation dynamics. Further, Sinclair and Zeppelin (2002) placed rookeries into four groups based on similarities in frequency of occurrence (% FO) of sea lion prey, and Smith (1988) suggested that rookery substrate type is important for determining the stability of Steller sea lion breeding territories.

It is our purpose to group Steller sea lion rookeries into potential management areas containing one or more rookeries based on their relatedness with respect to selected ecological attributes. Attributes were defined using three broad categories including habitat, diet data, and population trends. These factors were expanded and explored using current literature and NMFS databases, current literature within a Geographic Information System (GIS). Not all physical and biological factors important to Steller sea lions were included; only parameters with sufficiently complete data, both spatially and temporally, on sea lion rookeries were included.

METHODS

Study area

Sea lion rookeries generally consist of shoreline areas where pups are born during the breeding season (May through August). Our analysis included 38 rookeries from the western stock of Alaska Steller sea lions (Bickham *et al*., 1996) and two rookeries (Forrester and Hazy Islands) from the eastern stock. Oceanographic features used to characterize this area include primary ocean currents (Alaskan Stream, Alaska Coastal Current, Aleutian North Slope, and the Bering Sea Slope), bathymetry (from continental shelf to oceanic basins), and major oceanographic passes between Aleutian Islands, which provide an important link between the North Pacific Ocean and Bering Sea (Fig. 2).

Analysis

We used available literature, NMFS datasets, and GIS resources to group rookeries into ecological regions. Datasets were initially divided into the three broad categories (habitat, diet, and population) and then subdivided. Habitats were categorized according to depth, mean sea surface temperature (SST) from 1995 to 2000 during the breeding season, substrate type, and rookery shoreline compass orientation. Diet was described as diet diversity % FO of prey in sea lion fecal samples (scats) collected in the study area from 1990 to 1998. Sea lion abundance was calculated from counts of sea lion non-pups obtained over the same time period (Table1).

Habitat

Bathymetry: Digitized soundings from the National Image and Mapping Agency (NIMA, Bethesda, MD) records were used to calculate the mean depth within 10nm radius (1 nm = 1.85 km) of each rookery. These data were limited to areas east of 180^{o} longitude. Sounding data from the National Ocean Service (NOS, Seattle, WA) database were used to calculate mean depth west of 180^{o} to Attu Island. Point data were spatially joined to the buffered rookery polygons and converted to the respective raster layer. The mean depth within the buffered area was assigned to each rookery.

Temperature: Monthly average sea surface temperatures from May through August (breeding season) between 1995 and 2000 (best available dataset) were obtained from the European Space Agency's (ESA) ERS 2satellite. (http://odisseo.esrin.esa.it/asst-cgi/welcome.cgi,2004). The onboard Along Track Scanning Radiometer sensor passively collects radiometric data, which is converted to SST using thermal-infrared bands (3.7, 10.8, and 12.0 μm). The resultant data were atmospherically corrected and clouds were masked. Monthly temperature maps, provided by the ESA, are an average of the values for each geographic point over the entire month. Data cells have a spatial resolution of 0.5^{o} latitude and cover the globe. Temperature data were sampled out to10 nm from each rookery to match the scale of our analysis (Fig3). To test the effect of the strong 1997 El Niño (Napp *et al.* 2002; Stabeno *et al*., 2001) we calculated the mean SST temperature including and excluding temperature values from 1997. Mean SST differences were ± 0.5°C between the El Niño year and the non-El Niño years. Therefore, we included 1997 in the final analysis.

Substrate type: This category represents the dominant substrate material at a rookery and was divided into five categories: offshore rock, slab rock, rock/boulder beach, cobble beach, and sandy beach. These data can be considered as occurring along a continuum where boulder beach, rock slab, and offshore rocks are more similar than cobble beach and sandy substrates. Offshore rocks are relatively small, rocky areas, which are not part of the continuous shoreline of an island or the Alaska Peninsula. We determined substrate type utilizing existing data (NMFS database) and by visually inspecting photographs of each sea lion rookery.

Orientation**:** The orientation of a rookery was described as the compass direction of the rookery shoreline and included: N, NE, E, SE, S, SW, W, and NW (denoted in degrees for analysis). We also described rookeries that were exposed in all directions or rookeries having broad exposure (e.g. SW, S, SE).

Diet

Diet Diversity**:** We used published (Calkins, 1998; Merrick *et al.*, 1997; Sinclair and Zeppelin, 2002) and unpublished NMFS diet data obtained from scats collected from 1990 to 1998 within the study area to describe sea lion diets. Scat data analysis only used prey species having >5% FO (Sinclair and Zeppelin, 2002). Scats were collected on rookeries during the breeding season (May through August) and were assumed to represent adult female and some juvenile animal diets.

We identified prey to the lowest common taxonomic denominator (family) with the exception of cephalopods (class). Diet diversity (N1) was calculated using a Hill's (1973) index (Ludwig and Reynolds, 1988), which is based on Shannon information theory (H') and where:

$$N1 = e^{H'} \qquad (1)$$

$$H' = -\sum \left(\frac{n_i}{N}\right) \ln\left(\frac{n_i}{N}\right) \qquad (2)$$

and n_i is the number of prey in family *i*, N is the total number of prey. Unidentified species were not included. Hill's (1973) diet diversity number is linearly related to the proportional abundance of prey at sea lion rookeries. We chose Hill's measure of diversity because the units are equal to the lowest taxonomic level identified (family) and therefore were easy to interpret.

Population

<u>Count data:</u> York *et al.* (1996) conducted hierarchical cluster analysis on population counts of non-pups in mid June for the years 1975-1994. Rookery locations fell into five groups based on similarities in rates of population decline. However, their clusters were based on the distance of each rookery from Outer Island, a rookery near the Kenai Peninsula. By weighting their clusters by distance, they eliminated the possibility of independent rookery clusters that are widely separated. We based our analysis on population dynamics at the respective rookeries, independent of other sites. General trends in populations for rookeries were calculated using non-pup counts 1990-1998.

The natural logarithm of sea lion counts was plotted by year and simple liner regression was used to estimate the rate of change over time (Loughlin and York, 2000; York *et al.*, 1996).

Spatial analysis

The ecological parameters described above were managed in a GIS database (ArcGIS 8.0, ESRI, Redlands, CA). Each ecological attribute was imported as a separate layer and projected as NAD_1983_Albers. Rookeries were buffered (10-nm radius) and each ecological attribute was assigned to the rookery buffered area and converted to individual grid layers, one for each ecological variable. Areas that had no data and/or land features were excluded from the analysis. Individual layers were combined using the Raster Calculator GRID functions in ArcGIS, creating a single composite grid layer containing values representing the ecological attributes assigned to each rookery. These unique values, representing the combined attribute layers, were used for the cluster analysis.

In a spatial context a cluster is defined as a set of contiguous units that are assigned to the same class (Armstrong *et al.*, 2003) and is used an a exploratory tool to determine natural groupings in the data. Ecological regions were determined in ArcGIS using Jenks (1977) optimal-break classification algorithm, which is a statistical method used to identify natural breaks in the data. This method, similar to other discriminate analyses, creates an optimal number of classes in the data by minimizing the variance within class and maximizing variance between classes (Slocum, 1999). This is done through the goodness of variance fit (GVF), where the smallest sum of squared deviations from class means is sought (Dent, 1996). The calculation is made only on the attribute data associated with each rookery independent of geographic location, and the user determines the number of classes. The result of the analysis is a choropleth map of the groups displayed in ArcGIS.

The number of appropriate classes for the Jenks classification was determined by computing the goodness of absolute deviation fit (GADF, Slocum, 1999), defined as:

$$\text{GADF} = 1\text{- ADCM/ADAM} \qquad (3)$$

where ADCM is the sum of absolute deviations about the class medians and ADAM is the sum of absolute deviations about the median of the entire data set. They are given by the following equations (Robinson *et al.*, 1978):

$$\text{ADAM} = \sum_{i=1}^{n} \left| Z_i - Z_m \right| \qquad (4)$$

$$\text{ADCM} = \sum_{j=1}^{k} \sum_{ij=1j}^{nj} \left| Z_{ij} - Z_{mj} \right| \qquad (5)$$

GADF values range from 0 to 1, with 0 representing the lowest accuracy and 1 the highest. If the data are random then GADF will only equal one when each observation is in a separate class. One approach to selecting the appropriate number of classes from this calculation is to graph the number of classes against the GADF value (Slocum, 1999). The point where the curve begins to level off indicates that a larger number of classes would not contribute to a significant reduction in the classification error (Fig. 4).

The result of the optimal breaks algorithm is a map where individual rookeries are assigned to groups based on their relatedness to the ecological attributes we defined. In addition to the classification map, we calculated within and between group variances to show whether classes are similar or different. We also calculated Jenks indicator (Jenks, 1977), which is a measure of the overall accuracy of the classification and is defined as the sum total of absolute deviations of each class divided by the number of classes. The closer the value is to one the better the algorithm classifies the data.

RESULTS

Habitat

The mean depth within 10 nm of all rookeries was 163 m (± 38 m) and the mean depths of individual rookeries ranged from 32 m to 1541 m (Table 1). Mean SST throughout the study area was 6.5^{o} C (± 0.3) and ranged from 4.0^{o} C to 11^{o} C at different rookeries (Fig. 3). Most rookeries are described as having either rock/slab or cobble beach substrate. Only two of the 40 rookeries sampled have a sandy beach substrate. Rookeries tend to be oriented toward the adjacent ocean. For example, rookeries on the south side of the Alaska Peninsula generally face south towards the Pacific Ocean. North or west-facing rookeries are rare (Table 1).

Diet

Diet diversity varies throughout the Aleutian Islands and GOA (range 1.0 - 11.5). Areas having the highest diet diversity include the rookeries near Unimak Pass (mean 6.6, range 4.1 -11.5), where walleye pollock (*Theragra chalcogramma*), Pacific herring (*Clupea pallasi*), salmon (*Oncorhynchus spp.*), and some Atka mackerel (*Pleurogrammus monopterygius*) are common components of the diet. Sea lions on Sea Lion Rock near

Amak Island, the only rookery located north of the Alaskan Peninsula in the Bering Sea, had the highest diet diversity (11.5). Animals in the western Aleutian Islands tend to feed off the continental shelf and have the lowest diet diversity (mean 3.4, range 1.0 - 4.1) consisting largely of Atka mackerel and cephalopods. Near Kodiak Island diet diversity values had a mean of 4.4 and ranged from 3.3 to 6.0. Scats collected from rookeries near Kodiak Island consisted largely of herring, pollock, salmon, and arrowtooth flounder (*Atheresthes stomias*).

Population

Trend direction and strength was variable and from 1990 to 1998, population trends for rookeries ranged from a decline of -12% to a +3.7% increase. The mean trend throughout the range was a -5 % (± 0.61) decline (Table 1). This was consistent with the rate of decline calculated by Loughlin and York (2000) for counts conducted between 1991 and 2000.

Spatial analysis

The graph of GADF values vs. the number of classes (Fig. 4) resulted in a curve that begins to level off at five rookery classes. Therefore, we grouped sea lion rookeries into five regions, which were related based on the ecological attributes we defined (Table 2). The mapped result of the Jenks optimal classification is shown in Fig. 5a, b. Regions were subjectively assigned numbers 1 through 5 from west to east. The within and between group variances is given in Table 2. The Jenks indicator was 0.973, indicating a good overall classification of the data.

DISCUSSION

Our results suggest that Steller sea lion rookeries can be grouped into regions based on similarities in ecological parameters. The oceanic basin and shelf waters of the Bering Sea and North Pacific Ocean are dynamic, diverse, and highly productive areas. The physical properties of these systems affect primary production, prey distribution, and ultimately the foraging success of Steller sea lions. Ecological boundaries that we found between sea lion rookery groupings are consistent with shifts in the biophysical oceanographic properties of the Aleutian Arc (Ladd *et al*., in press), patterns in demersal ichthyofauna distributions (Logerwell *et al*., in press), and shifts in sea bird diets (Jahnke *et al*., in press).

Currents

Although currents were not measured directly for the analysis, the physical structure of the primary currents is related to continental shelf geometry (bathymetry) and has distinct temperature structures (Reed and Stabeno, 1989; Stabeno and Reed, 1993; Stabeno *et al.*, 1999; Stabeno *et al*., 2002; Warren and Owens, 1988). The Alaskan Stream forms the northern boundary of the Pacific sub arctic gyre and extends from the GOA to the western Aleutian Islands (Favorite *et al*., 1976; Reed, 1984). Drifter buoy data (Stabeno and Reed, 1993) indicates the Alaskan Stream turns northward near Amchitka Pass, following the bathymetry and becomes the Aleutian North Slope Current (ANS), which flows westward along the northern side of the Aleutian chain (Stabeno et *al*., 1999). The Alaska Coastal Current (ACC) is characterized by warmer more saline waters and flows southward in the GOA (Royer *et al*., 1979), nearshore along the south side of the Alaskan Peninsula and links to the shelf waters of the eastern Bering Sea through Unimak Pass (Stabeno *et al.*, 1995; Stabeno *et al*., 2002). There is evidence that a portion of the ACC continues along the Aleutian Islands until it reaches Samalga Pass (Ladd *et al*., in review).

Steller sea lion regions defined here appeared to be associated with major ocean currents (Fig. 5a). Our results suggest that the difference in the temperature structure and depth of the primary currents is important in distinguishing our regions. For example, deep water and cold SST, properties shared by the Alaskan Stream and ANS currents, characterize regions 1 and 2. Rookeries in these regions may be described by more oceanic than coastal water properties. Conversely, regions 3, 4, and 5 are influenced by the shallow and nearshore ACC.

Not surprisingly, the distribution of Steller sea lion rookeries across the North Pacific Ocean rim tends to cluster near major oceanic currents, particularly when one considers the relationships between currents and the resultant ecological boundaries produced. Ecological boundaries (e.g. edges, ecotones, borders) share three defining features: 1) they are three-dimensional zones of transition between contrasting systems, 2) the gradient in the feature setting up the contrast is steeper in the boundary than in the two adjoining systems, and 3) boundaries can be wide or narrow, reflecting the steepness of the gradient (Cadenasso *et al.*, 2003). In the marine environment, ecological boundaries occur at the transition between oceanic currents, gyres, and eddies and frequently tend to focus nutrients, which in turn tend to concentrate prey and predators. For instance, Polovina *et al.* (2000) report on nine loggerhead sea turtles (*Caretta caretta.*) that traveled along two convergent oceanic fronts and may have used these boundaries as a cue to locating prey, as a navigational aid, or perhaps as an aid to swimming. Eddies (Piatt *et al.*, 1992), tidal mixing (Coyle *et al.*, 1992; Hunt *et al.*, 1998), and boundaries between large water masses (Elphick and Hunt, 1993; Hunt, 1997) affect productivity, aggregate prey, and determine where marine birds forage. Loughlin *et al.* (1999) speculate that adult male northern fur seals (*Callorhinus ursinus*) follow sea surface currents as an aid to finding prey and that their movements tended to concentrate at the boundaries of the subarctic gyre or major oceanic currents. It is likely that Steller sea lions also use these physical attributes to locate prey and to aid in navigation. Because Steller sea lions tend to feed nearshore, especially during the breeding season (Loughlin *et al.*, 2003; Merrick and Loughlin, 1997), they likely cue on ecological boundaries associated with currents moving along the Alaska Peninsula and Aleutian Island chain.

Passes

Oceanographic passes along the Aleutian Archipelago provide an important connection between the North Pacific Ocean and the Bering Sea. The depth and width of the passes (Schumacher and Stabeno, 1998), strong tidal mixing (Coyle *et al*., 1992), and the general northward flow of water through the central and eastern Aleutian Passes (Reed and Stabeno, 1989; Stabeno and Reed, 1993; Stabeno *et al*., 2002) play an important role in providing nutrients to the southeastern Bering Sea (Stabeno *et al*., 2002) and shaping the marine environment of the Aleutian Arc.

Samalga Pass is an important dividing line of physical features in the North Pacific Ocean and is described as a transition zone between the continental shelf and ocean passes (Ladd *et al*., in review)**.** Passes east of Samalga (eastern passes) tend to be narrower and shallower (≤150 m) having warmer and fresher water than those to the west (central and western passes). Areas to the west of Samalga Pass are described as "oceanic" (Ladd *et al*., in review) and have deeper, cooler, more saline waster then passes to the east (Ladd *et al*., in review). Transport of water between the North Pacific and Bering Sea is generally northward in the eastern passes. However, the deeper, wider passes of the central and western Aleutians allow mixing both north and southward. In addition, the width of the North Pacific shelf decreases as it extends west from the Alaskan Peninsula to the Aleutian Island chain. A significant decrease occurs west of Samalga Pass**.** Logerwell *et al.* (in press) found that abundance and growth rates of fish species are lower in areas west of Samalga Pass than to the east. This is consistent with the evidence that chlorophyll levels decline west of the pass and with difference in diet diversity between our regions.

Changes in oceanographic properties among passes are reflected in the clustering of sea lion rookeries. Our regions suggest a dividing line between rookeries east and west of Samalga Pass, with rookeries west of the pass generally having stronger rates of decline, lower diet diversity, associated with colder SST, and occurring near deeper water. These regions (1 and 2) are associated with more oceanic physical oceanographic properties (Ladd *et al*., in review) than coastal. It is reasonable that Bogoslof Island, which is east of Samalga pass would group with region 2 because it is located off the continental shelf in the deep oceanic basin of the Bering Sea. The regions to the east of the pass are characterized by a more stable population, higher diet diversity, warmer SST, and shallower than regions to the west. Physical and biological oceanographic properties are more variable of east of Samalga Pass and in the GOA then in the western Aleutian Islands and are reflected in rookery groups.

Unimak Pass is a major connection between the North Pacific and eastern Bering Sea, transporting the warm, low saline waters of the ACC to the Bering shelf. The result is a highly dynamic and productive area (Stabeno *et al.*, 2002). Steller sea lion rookeries in this region have the highest diet diversity and the slowest rates of decline of the rookeries in our analysis. Merrick *et al.* (1997) and Sinclair and Zeppelin (2002) suggest a similar relationship between diet diversity and population trends near Unimak Pass. Hunt *et al*. (1998) reported the tidal flow and production of the Aleutian Passes influenced where three species of auklets aggregated and foraged. They found that least (*Aethia pusilla*), crested (*A. cristatella*), and parakeet (*A. psittacula*) auklets timed their foraging in a pass to correspond with tidal currents. This is due to the geometry (shallow and narrow) of the eastern Aleutian Passes, which drives tidal processes and aggregates prey. Presumably, the geometry and physical structure of passes aggregate prey that are important to sea lions and is reflected in our region breaks (Fig. 5b).

The high variability in regions 3 and 4 may be attributed to more diversity in the types of prey utilized by sea lion in these areas. Regions 1 and 2 are tightly grouped, have clear breaks at Aleutian passes, sea lions in the region consume very few different prey families. On the other hand, sea lions at rookeries in regions 3 and 4 have more variability in their diet clustering reflecting the higher diversity of prey items that they consume.

It is interesting to compare the high number of Steller sea lion rookeries within the study area (44) to the restricted number of northern fur seals breeding locations (3 islands). The fact that northern fur seal breeding is restricted to the Pribilof Islands and Bogoslof Island (since 1981) may be linked to the foraging distribution of adult females during the breeding season and the oceanic domains within which they depend. Adult female northern fur seals typically forage as far as 200 km from the breeding rookery and are spread throughout the southeastern Bering Sea (Loughlin *et al.*, 1987; Goebel *et al.*, 1991). Steller sea lions are more restricted in their feeding trips; adult females during the breeding season typically forage within 20 km (range 3 - 49 km; Merrick and Loughlin, 1997) of the breeding rookery and remain nearshore.

We measured the distance between rookeries within our study area and found distances averaging approximately 108 km apart, but many were separated by 60 km or less. Distance between rookeries was greatest in the western Aleutians islands (region 1). We speculate that the distance between rookeries may be related to the foraging distance of lactating females during the breeding season as a result of intraspecific competition when sea lions numbers were high and competition for prey was perhaps more intense. Because female sea lions with suckling pups typically feed within 20 to 25 km (exceptionally to 50 km) from the rookery, we assume that natural selection resulted in a buffer of a few km between sites where females will not compete for prey during the breeding season. Because these rookeries cover such a broad geographic range, different ecological and environmental factors likely influenced their location and orientation resulting in the groups or clusters proposed here.

With regards to management of sea lions over a large oceanic area, there are spatial scales on which we would expect community composition to change. Habitat suitable for Steller sea lion rookeries can be defined by water masses (large ocean basins), the physical features within water masses (currents, bathymetry, temperature, salinity), and biological features (prey availability) driven by physical processes.

Defining management regions for Steller sea lions is a complex decision-making matrix, which should include attributes similar to what we have defined. Our results suggest that Aleutian Islands rookeries west of Samalga Pass could be managed as two units (ecological regions 1 and 2) with breaks at Amchitka Pass and Samalga Pass; these units are similar to those defined previously based on island groupings (central and western Aleutians). In our analysis these units grouped together based on low diet diversity and population declining trends and are consistent with published summaries linking these areas (e.g., Sinclair and Zeppelin, 2002; York *et al.*, 1996). Habitat type and physical oceanography are somewhat homogenous within these units and the differential gradients separating these units are defined by the two island passes (Amchitka and Samalga). These in turn likely influence prey diversity and availability to Steller sea lions.

Regions east of Samalga Pass (ecological regions 3-5) are more complex and do not separate as cleanly as those in the Aleutians, primarily based on higher diet diversity, which is likely driven by the complex oceanography associated with a wider continental shelf and variable flow and direction of currents. Thus, management units based on ecological regions east of Samalga Pass is more problematic. It is interesting to note, however, that the rookery groupings east of Samalga Pass in our analysis are similar to those in the cluster analysis based solely on population trends in York *et al*. (1996). The clusters of nearby rookeries such as Marmot/Sugarloaf, Chernabura/Atkins, Clubbing/Pinnacle, and those within the Unimak Pass area in our analysis suggest a more unifying collection of factors linking these sites than merely population trends. In the current scheme of fisheries management in the Gulf of Alaska and Bering Sea, designed to protect Steller sea lion critical habitat and sea lion prey, recognition of these rookery linkages and the ecological factors that drive these linkages need to be considered when proposing season and area take levels for fish consumed by sea lions.

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Figure 1. Eight management regions currently used for describing the population status and trends of Alaskan Steller sea lions. The rookeries in these regions are grouped based solely on a rookeries proximity of geographic features.

Figure 2. Our study area, including bathymetry, major Aleutian Island passes, and the region's primary currents (Alaska Coastal Current (ACC), Alaskan Stream, Aleutian North Slope, and the Bering Slope Current).

Figure 3. Mean sea surface temperature (SST) for the study area during the breeding season (May-Aug) from 1995 to 2000.

Figure 4. Goodness of absolute deviation (GADF) curve indicating the appropriate number of classes to use in the Jenks' classification analysis. As the curve begins to level off adding additional classes will not significantly reduce classification error.

Figure 5. The five ecological regions, determined by the Jenks classification, mapped in relation to (a) mean ocean currents and SST of the North Pacific, Bering Sea, and GOA, and (b) in relation to the major Aleutian Island passes.

Table 1. Summary of the ecological variables used for our analysis, listed by rookery and the regions to which they were assigned as a result of the Jenks' classification. Region groups were numbered 1 through 5 from west to east, consistent with Fig 5a,b.

Region	Rookery	Mean depth (m)	Mean SST (^oC) (1995 - 2000)	Substrate type	Compass orientation	Diet diversity	% Population trend (1990 -1998)
1	Agattu (Cape Sabak)	66	6	boulder beach	S	3.2	-4.1
	Agattu (Gillion Pt)	82	6	boulder beach	S,SW	3.5	-4.7
	Amchitka (East Cape)	104	5	rock/slab	ALL		0.7
	Amchitka (Column Rock)	89	4	rock/slab	E	3.0	-9.1
	Attu (Cape Wrangell)	221	6	boulder beach	SW	2.2	-3.7
	Ayugadak	149	4.5	cobble beach	SE		-10.2
	Buldir	415	5	offshore rock	SW	2.8	-3.8
	Kiska (Cape St Steven)	174	4	cobble beach	S,SW	3.0	-7.2
	Kiska (Lief Cove)	75	4	cobble beach	W,NW	2.9	-2.6
	Semisopochnoi (Petrel)	65	4.6	boulder beach	E		
	Semisopochnoi (Pochnoi)	259	4.5	rock/slab	E	4.1	-4.7
2	Adak (Lake Pt)	179	5	rock/slab	SW	3.0	-7.4
	Agligadak	114	5	offshore rock	S		-8.0
	Amlia	78	5	rock/slab	S,SW,SE	1.0	-2.9
	Bogoslof	1541	6	sandy beach	S,SW,SE	6.1	-4.7
	Gramp rock	270	5	rock/slab	SE	3.6	-6.7
	Kasatochi (North Pt)	476	4.5	rock/slab	N	6.3	-4.3
	Seguam (Saddleridge)	156	4.5	cobble beach	N	3.7	-8.2
	Tag	165	5	rock/slab	S	2.9	-5.0
	Ulak (Hasgox Pt)	259	5	rock/slab	ALL	3.3	-7.8
	Yunaska	162	5.5	cobble beach	E	4.8	-7.6
3	Adugak	159	6	offshore rock	ALL	4.6	-12.4
	Akutan (Cape Morgan)	47	6.5	sandy beach	SE	5.6	-8.9
	Atkins	50	8	boulder beach	S	2.9	-10.4
	Chernabura	58	7.5	rock/slab	S	3.2	-1.8
	Chirkof	55	8.5	cobble beach	S	4.2	-9.9
	Marmot	48	8	cobble beach	E	6.0	-11.3
	Ogchul	82	6.5	rock/slab	SE	2.7	-1.5
	Ugamak and Round	63	6	cobble beach	S,N	6.0	-4.2
	Forrester	84	10	rock/slab	ALL		1.3
	Hazy	71	10	rock/slab	N,NW		3.7
	Sugarloaf	83	8.5	boulder beach	N,NE	6.6	-3.5
	Wooded (Fish)	71	10.5	boulder beach	NE,SE		-7.5
4	Akun (Billings Head)	71	6	cobble beach	N	6.1	2.1
	Chowiet	102	8	rock/slab	SE	4.1	-6.4
	Clubbing rocks	51	7	rock/slab	ALL	6.9	-1.4
	Pinnacle rock	56	8	rock/slab	ALL	4.6	-5.4
	Sea Lion rock (Amak)	32	6.5	offshore rock	S	11.5	1.8
	Seal rocks	146	11	cobble beach	ALL		-3.1
5	Outer	96	10	boulder beach	S,SE		-5.9

Table 2. Mean and standard error of each numeric ecological attribute by region and within and between region variance values.

Ecological regions	SST(^{o}C)	Depth (m)	Diet diversity	Population trend	Within group variance	Between group variance
Region 1 (Attu Is. to Amchitka Pass)	4.8 ± 0.2	154 ± 33	3.1± 0.2	-4.9% ± 1%	5717	149846
Region 2 (Ulak Is. to Yunaska Is.)	5.0 ± 0.16	340 ± 138	3.9 ± 0.6	-6.3% ± 0.6%	8983	900163
Region 3 (Adugak Is. to Hazy Is.)	8.0 ± 0.46	73 ± 9	4.6 ± 0.5	-5.5% ± 1.5%	96558	397258
Region 4 (Akun Is. to Seal Rocks)	7.8 ± 0.73	76 ± 17	6.7 ± 1.3	-2.1% ± 1.5%	456303	2018299
Region 5 (Outer Is.)	10	96	no data	-5.87%	n/a	n/a

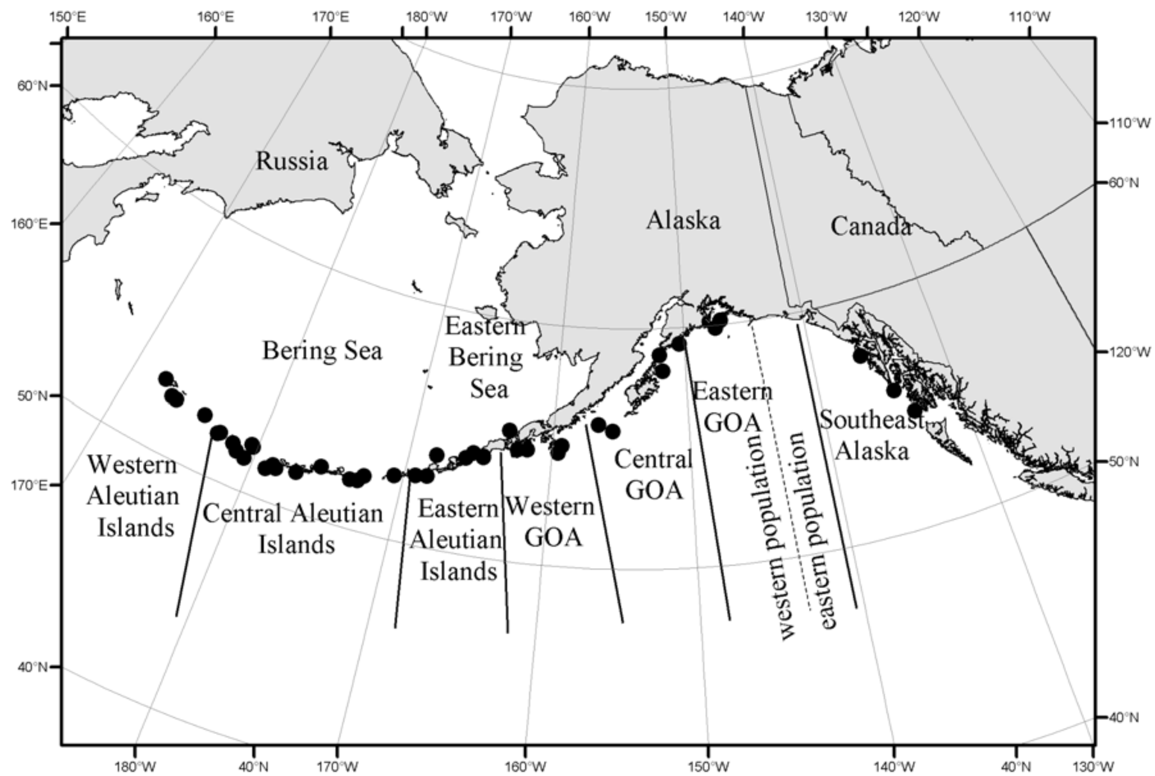

Russia
Alaska
Canada
Bering Sea
Eastern
Bering
Sea
Western
Aleutian
Islands
Central Aleutian
Islands
Eastern
Aleutian
Islands
Western
GOA
Central
GOA
Eastern
GOA
western population
eastern population
Southeast
Alaska

Fig. 1

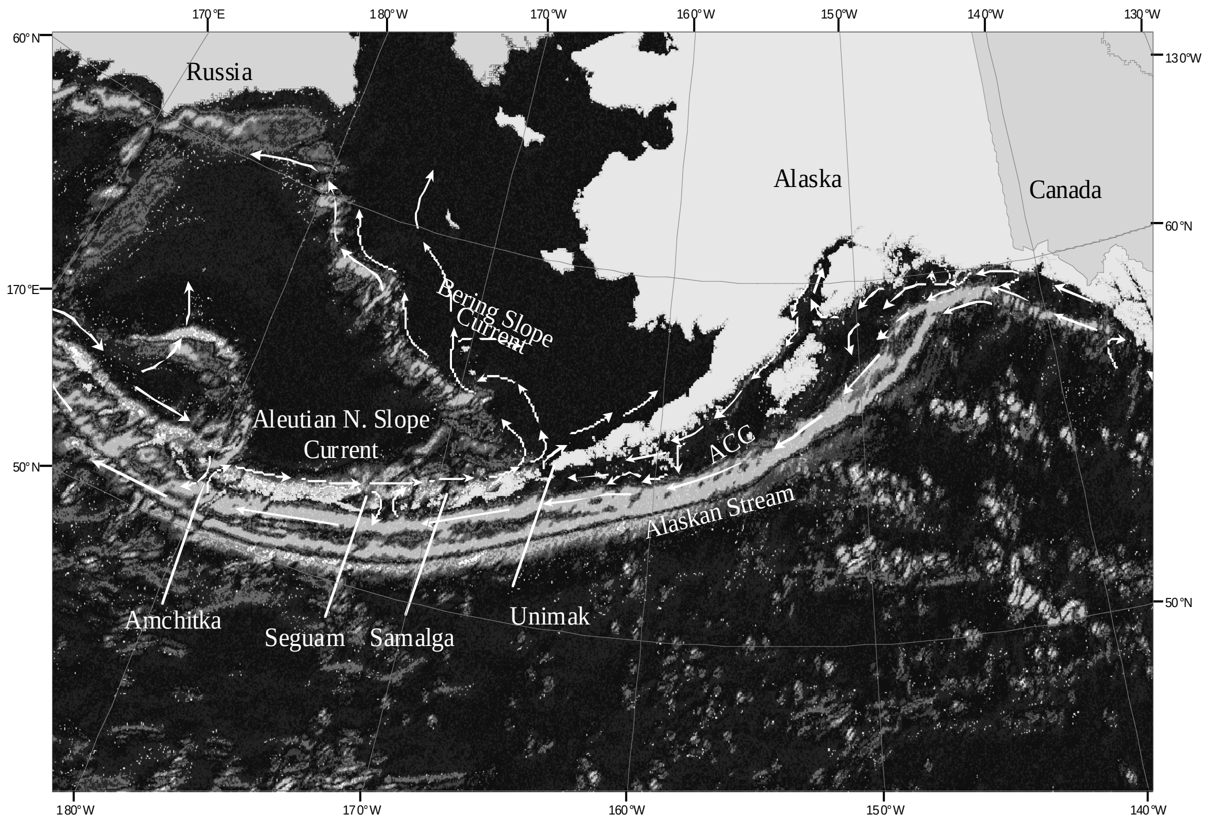
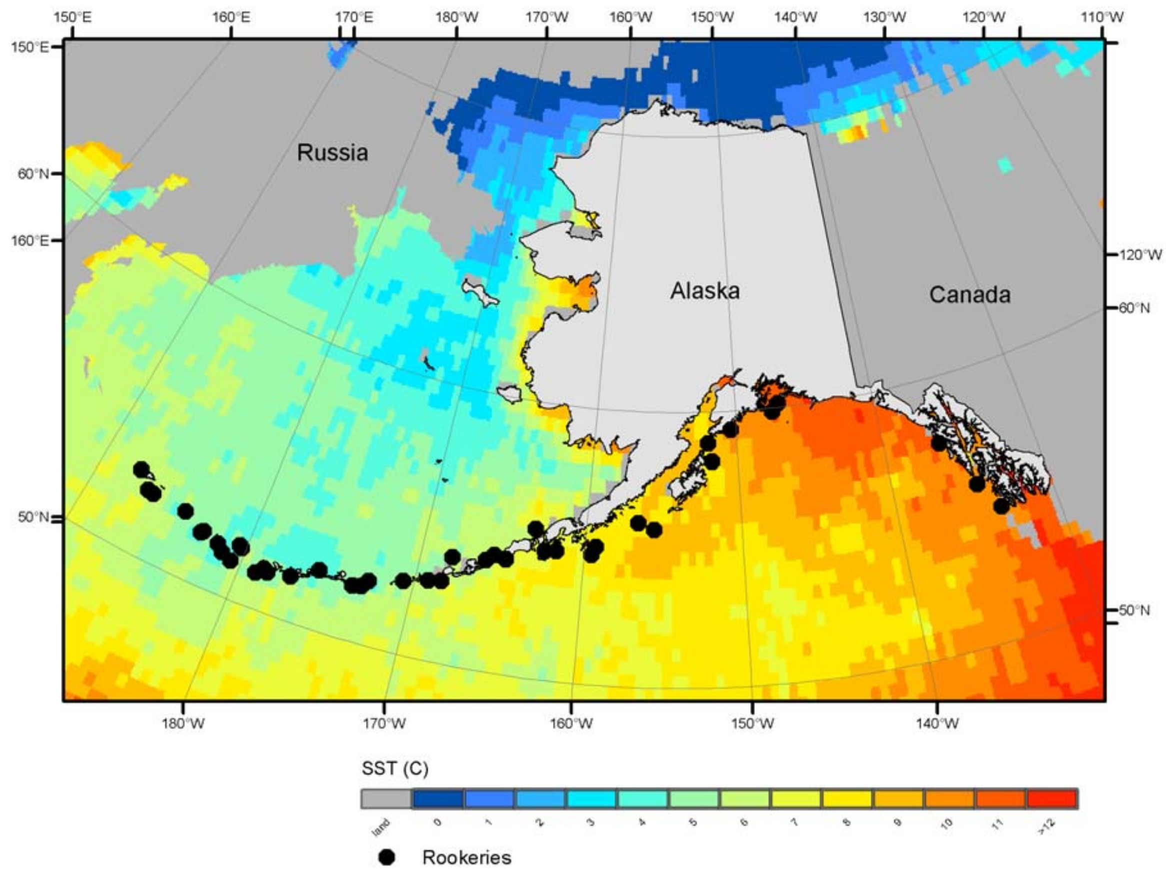

Russia
Alaska
Canada
Bering Slope
Current
Aleutian N. Slope
Current
ACG
Alaskan Stream
Amchitka
Seguam
Samalga
Unimak

Fig. 2



150°E
160°E
170°E
180°W
170°W
160°W
150°W
140°W
130°W
120°W
110°W
150°E
60°N
160°E
50°N
120°W
60°N
50°N
Russia
Alaska
Canada
180°W
170°W
160°W
150°W
140°W
SST (C)
land
0
1
2
3
4
5
6
7
8
9
10
11
>12
Rookeries

Fig. 3

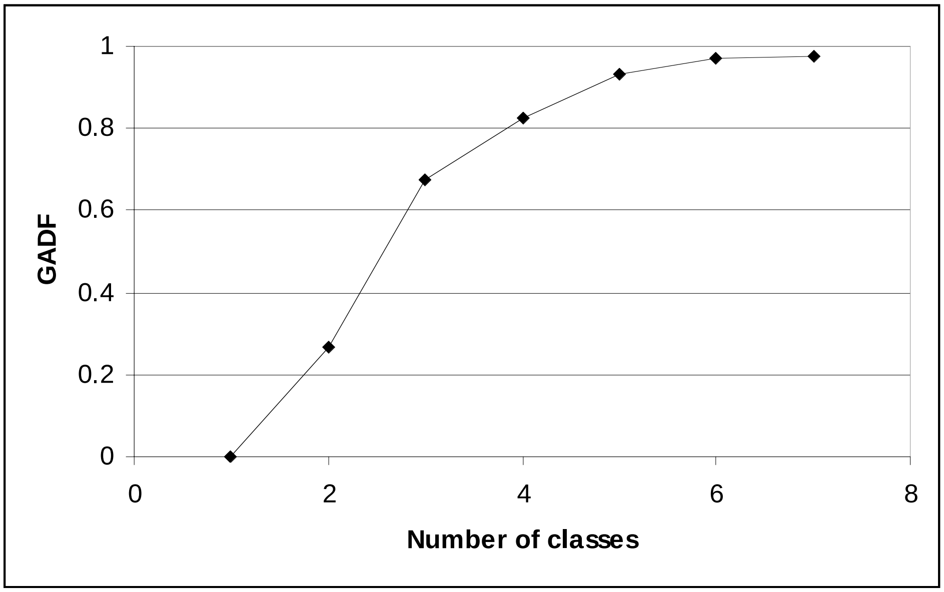


Fig. 4

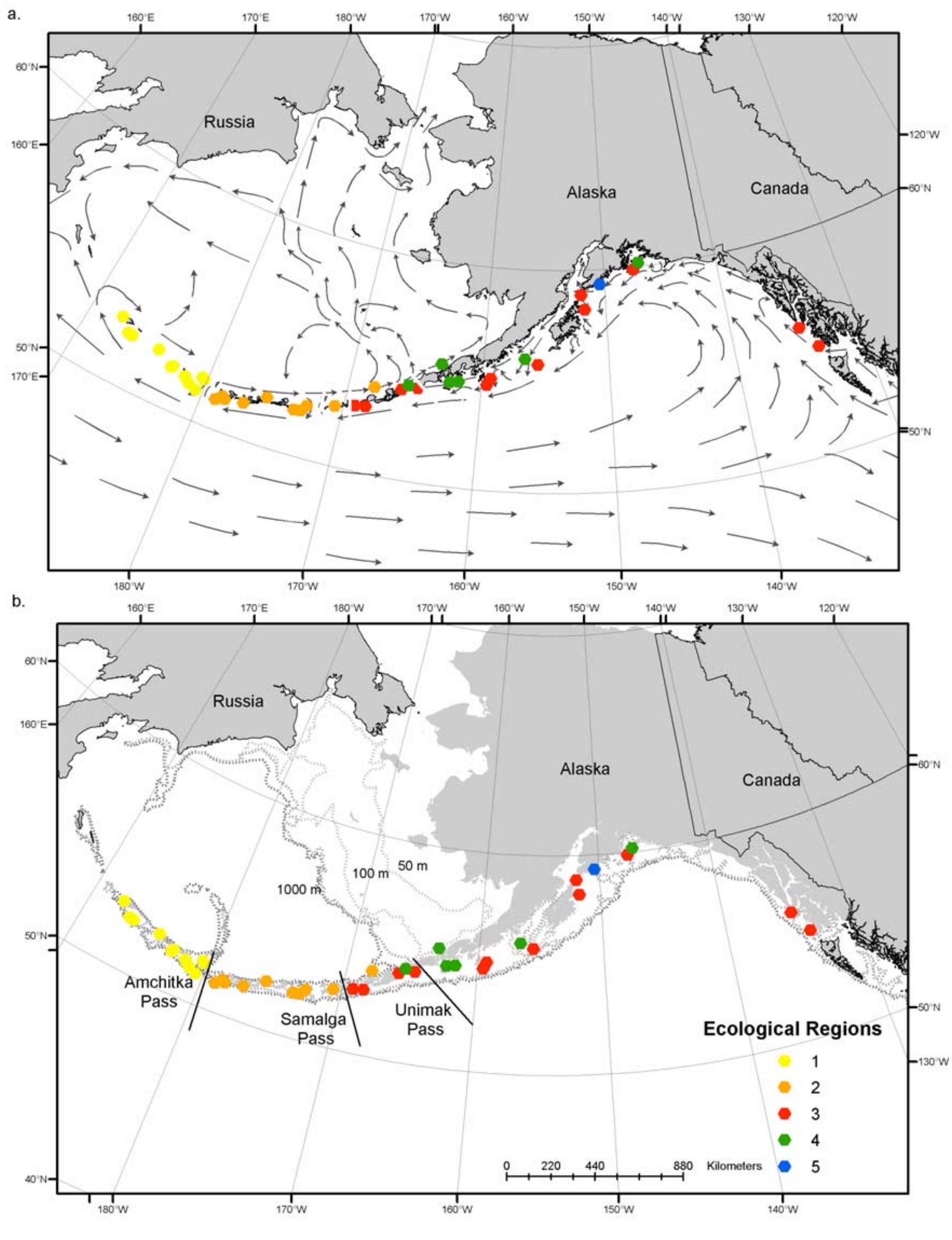

a.
Russia
Alaska
Canada
b.
Russia
Alaska
Canada
1000 m
100 m
50 m
Amchitka Pass
Samalga Pass
Unimak Pass
Ecological Regions
1
2
3
4
5
0 220 440 880 Kilometers

Fig. 5